PATENT SPECIFICATION

(11) 1 528 180

(21) Application No. 52428/75 (22) Filed 22 Dec. 1975
(31) Convention Application No. 544105
(32) Filed 27 Jan. 1975 in
(33) United States of America (US)
(44) Complete Specification published 11 Oct. 1978
(51) INT CL² G01S 5/12
(52) Index at acceptance
H4D 259 271 34X 562 566 593 632

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1 528 180

(19)

(54) COMPUTERS FOR USE IN AIRCRAFT

(71) We, SPERRY RAND CORPORATION, a Corporation organised and existing under the laws of the State of Delaware, United States of America, of 1290 Avenue of the Americas, New York, New York 10019, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to computers for use in aircraft radio based area navigation (RNAV), particularly with regard to OMEGA and VOR/DME RNAV aids.

VOR/DME radio navigation aids are utilized to provide latitude and longitude positional data to aircraft equipped with suitable RNAV receivers. A VOR/DME station utilizes a conventional VOR transmission system to provide bearing data to the aircraft with regard to the station location as well as a standard DME system to provide distance data to the aircraft with regard to the station. Analogue and/or digital equipment on board the aircraft converts the bearing and distance data with respect to the fixed location of the station into aircraft latitude and longitude positional data in a well-known manner.

The positional data provided by the VOR/DME RNAV aid is accurate when the aircraft is relatively close to the VOR/DME station but the accuracy deteriorates at substantial distances from the station. Such systems provide accuracies of several tenths of a mile within approximately ten miles of a station but have an error of from five to ten miles at distances of 100 to 200 miles from the station. An error no greater than approximately two miles is desired throughout the flight of the aircraft to permit reduction of air route lane widths.

Previous attempts at enhancing flight accuracy have involved the use of dual separated DME systems. Although more accurate than the VOR/DME system at significant distances from the stations, the DME/DME system requires two complete DME receivers (a DME receiver being more complex than a VOR receiver) as well as a significantly more complex way point or log definition based on the two DME stations which provide range vectors with a significant angle with respect to each other as compared to the substantially simpler VOR/DME navigation system. Alternatively, inertial navigation equipment with radio update when the aircraft is close to a station has been used in navigation systems but inertial navigation equipment is extremely expensive compared with the simpler radio systems.

As is known, OMEGA is a low frequency hyperbolic navigation system providing latitude and longitude positional data throughout the world. The OMEGA system achieves one to two mile accuracy, but OMEGA receivers require elaborate equipment to correct for propagation effects in order to achieve this accuracy, such propagation effects typically being of a slowly varying diurnal nature.

The present invention aims to provide a computer affording accurate positional data from a VOR/DME radio receiver and a basic OMEGA receiver without the elaborate propagation correction equipment.

According to one aspect of the invention there is provided a computer for use in aircraft and arranged or programmed to provide automatically a computed aircraft positional data signal in response to an OMEGA positional data signal from an OMEGA system, a VOR/DME positional data signal from VOR/DME apparatus tuned to a stationary VOR/DME facility and a range signal representative of the distance of the aircraft from the VOR/DME facility, comprising first summing means which are responsive to the VOR/DME positional data signal and the computed positional data signal and which provide a positional data error signal representative of the difference therebetween, OMEGA compensation means which are responsive to the positional data error signal and the

range signal and which provide an OMEGA compensation signal in dependence on the time integral of the product of the positional data error signal and an inverse function of the distance, and second summing means which are responsive to the OMEGA positional data signal and the OMEGA compensation signal and which provide the computed positional data signal in accordance with the algebraic sum thereof.

According to another aspect of the invention there is provided a computer for use in aircraft and programmed to provide automatically a computed aircraft positional data signal in response to an OMEGA positional data signal from an OMEGA system, a VOR/DME positional data signal from VOR/DME apparatus tuned to a stationary VOR/DME facility and a range signal representative of the distance of the aircraft from the VOR/DME facility, the computer being arranged to store a previous value of an OMEGA compensation signal, the current value of the OMEGA positional data signal to the previous value of the OMEGA compensation signal to provide a temporary computed positional data signal, subtract the value of the temporary computed positional data signal from the current value of the VOR/DME positional data signal to provide a positional data error signal, compute a gain value in accordance with an inverse function of the distance, multiply the value of the positional data error signal by the gain value to provide an inter-grand value, multiply the intergrand value by the time elapsed since the computation for the previous value of the OMEGA compensation signal and add the result to the previous value of the OMEGA compensation signal to provide an updated value of the OMEGA compensation signal, thereby performing a time integration of the positional data error signal at a gain determined by the third means, and add the updated value of the OMEGA compensation signal to the current value of the OMEGA positional data signal to provide the computed positional data signal.

The aforementioned object of the invention is thus achieved by an OMEGA-VOR/DME positional data computer that provides a computed positional data signal in response to corresponding OMEGA and VOR/DME positional data signals. The computer includes a circuit for providing an OMEGA compensation which is algebraically added to the OMEGA positional data signal to provide the computed positional data signal, the OMEGA compensation being derived in accordance with the difference between the VOR/DME positional data and the computed positional data. The gain of the OMEGA compensation circuit is controlled in an inverse relationship with regard to the range of the aircraft from the VOR/DME station.

Two computers according to the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram of one computer which is an OMEGA-VOR/DME positional data computer,

Figure 2 is a schematic block diagram of the other computer which is an OMEGA-VOR/DME positional data computer instrumented with a digital computer,

Figure 3 is a computer programme flow diagram for instrumenting the computations of the computer of Figure 2, and

Figure 4 is a flow diagram for operating the computer of Figure 2 in failure modes.

Referring to Figure 1, a schematic block diagram of an OMEGA-VOR/DME positional data computer is illustrated. The computer is disclosed in terms of a latitude computation. It will be appreciated that the longitude computation is performed in exactly the same manner. The latitude positional data from the OMEGA equipment is applied to a terminal 10 and is designated λ_o. The λ_o data is derived from a basic OMEGA radio receiver and is processed in any convenient and well-known manner into the proper format for application to the computer of Figure 1. The latitude data at the terminal 10 is applied as an input to a summing circuit 11 whose output is applied through a two-position switch 12 to provide the computed latitude output λ_c of the computer.

The latitude positional data from the VOR/DME system is applied to a terminal 13 and is designated λ_v. The λ_v data is derived from the VOR/DME system in any convenient and well-known manner to provide signals of the appropriate format to the computer of Figure 1. In a similar manner, the DME equipment provides an appropriate range signal R to a terminal 14 in accordance with the range of the aircraft from the VOR/DME facility to which the aircraft equipment is tuned. The λ_v data at the terminal 13 is applied as an input to a summing circuit 15. The output of the summing circuit 11 is applied subtractively as another input to the summing circuit 15. The output of the summing circuit 15 is applied through a gain block 16 as the input to an integrator 17. The range signal at the terminal 14 is applied as another input to the block 16 to control the gain thereof. The gain of the block 16, designated as k, is

controlled to have an inverse functional relationship with regard to the range from the aircraft to the VOR/DME facility. The gain k may be inversely proportional to distance or may vary in some other fashion than inversely proportional to distance. For example, the gain k may vary inversely with the square or cube of the range R for reasons to be later discussed. The block 16 is instrumented in any conventional manner to perform the desired function. For example, when the gain k is designed to be inversely proportional to R, the block 16 may be instrumented as a multiplier and a circuit for taking the reciprocal of R. The multiplier would then multiply the output from the summing circuit 15 by the reciprocal of R, thereby providing the inversely proportional relationship. Similar gain circuits are disclosed in U.S. Patent Specification No. 3,919,529.

The gain block 16 and the integrator 17 together form an OMEGA compensation circuit 20 for providing an OMEGA compensation signal, designated as δ. The OMEGA compensation signal δ from the integrator 17 is applied as an input to the summing circuit 11.

When the OMEGA receiver is inactive or the OMEGA data is invalid, a signal is applied from the OMEGA receiver (not shown) to a terminal 21 to position the switch 12 to the contact opposite that illustrated in Figure 1. When so positioned the λ_c output is connected directly to the terminal 13 for reasons to be discussed. The OMEGA invalid signal is also applied to a terminal 22 to clamp the integrator 17 for reasons to be discussed. In a similar manner when the VOR/DME equipment is inactive or the VOR/DME data is invalid the integrator 17 is again clamped via the appropriate invalid signal applied to the terminal 22.

It will be appreciated from Figure 1 that

$$\lambda_c=\lambda_o+\delta \qquad (1)$$

and that

$$\delta=\int k(\lambda_v-\lambda_c)dt \qquad (2)$$

substituting equation (2) into equation (1) yields

$$\lambda_c=\lambda_o+\int k(\lambda_v-\lambda_c)dt \qquad (3)$$

And taking the derivative with respect to time yields

$$\lambda^o{}_c=\lambda^o{}_o+k(\lambda_v-\lambda_c). \qquad (4)$$

Regrouping the terms yields

$$\lambda^o{}_c+k\ \lambda_c=\lambda^o{}_o+\lambda_v. \qquad (5)$$

It will be appreciated that if k is very large ($k\ \lambda>>\lambda^o$), then λ_c will tend to track λ_v, the VOR/DME derived latitude. If k is very small ($k\ \lambda<<\lambda^o$), then λ_c will tend to track λ_o. The first condition is desirable near a VOR/DME facility where the VOR accuracy is high. The second condition is desirable at large distances where OMEGA is significantly more accurate than VOR. Consequently, k is made to vary inversely with respect to the distance R from the aircraft to the VOR/DME facility, e.g. inversely proportional with respect thereto as follows:

$$k=k_1/R \qquad (6)$$

where k_1 is a constant.

Substituting equation (6) into equation (3) yields

$$\lambda_c=\lambda_o+k_1\int\frac{(\lambda_v-\lambda_c)}{R}\,dt \qquad (7)$$

Thus it will be appreciated that with the appropriate instrumentation for the block 16 as described above, equation (7) describes the implementation of the OMEGA-VOR/DME positional data computer of Figure 1.

In operation when the VOR/DME and the OMEGA data are valid, the switch 12 is positioned as illustrated in Figure 1 and the integrator 17 is unclamped. When the aircraft is relatively near a VOR/DME facility, the gain through the block 16 is adjusted to be high and therefore the computer of Figure 1 rapidly forces the output δ from the integrator 17 to be equal to the difference between the OMEGA derived data and the terminal 10 and the VOR/DME derived data at the terminal 13. Thus the term δ is a compensation that is added to the OMEGA data by means of the summing circuit 11 to provide the computed data λ_c which at close proximity to a VOR/DME facility is equal to the accurate λ_v data. As the aircraft departs from the vicinity of a VOR/DME station, the gain through the block 16 is diminished. When the aircraft is at a substantial distance from the VOR/DME station the gain k through the block 16 is small so that inaccuracies of the λ_v data at the large flight distances from the VOR/DME facility have a diminished effect on the value of the OMEGA compensations stored in the integrator 17. Thus, although the accuracy of the λ_v data has deteriorated, the value of the OMEGA compensation δ that is added to the OMEGA data λ_o still retains the accuracy accumulated when the aircraft was near the VOR/DME station because of the decoupling effect of the diminished gain through the block 16. It will be appreciated

that although an inversely proportional relationship as discussed above with regard to the block 16 will provide adequate decoupling, the scale factor k utilized in determining the relative authorities of the OMEGA and the VOR/DME data may be varied in some other fashion than inversely proportional to distance. For example, k may be varied inversely with the square or cube of the distance to decouple more sharply the OMEGA data at long distances from the VOR/DME facility. In the event of failure of the VOR/DME equipment which invalidates the associated data or in the event of momentary interruption of the VOR/DME data such as when tuning to a new station, a signal on the lead 22 clamps the integrator 17, thus fixing the presently stored value of the OMEGA compensation δ. Thus the OMEGA data λ_o at the terminal 10 continues to be properly compensated by the fixed value of δ which is the last valid value thereof.

Similarly when the OMEGA data λ_o is invalid, a signal at the terminal 22 again clamps the integrator 17 and a signal at the terminal 21 transfers the wiper of the switch 12 to the position opposite that illustrated in Figure 1 to connect the output λ_c directly to the VOR/DME data λ_v at the terminal 13. Alternatively storage means (not shown) may be utilized to store the latest value of λ_o to be utilized in the event of a failure in the OMEGA data. The integrator 17 is clamped when the OMEGA data fails to preserve the last valid value of the OMEGA compensation δ for use when the system is again functioning properly.

When both the VOR/DME and the OMEGA data are invalid, the output of the computer of Figure 1 may be switched by means not shown to dead reckoning equipment such as that disclosed in the aforesaid U.S. Patent Specification No. 3,919,529.

It will be appreciated from the foregoing that the computer of Figure 1 utilizes complementary mixing of the OMEGA and VOR/DME data to combine the desirable characteristics of each navigation source to provide high accuracy flight latitude and longitude positional data while not requiring complex OMEGA propagation corrections. Thus a simple OMEGA receiver is utilized without the usual highly complex electronic circuitry for correcting the diurnal errors associated with OMEGA transmissions. It will be furthermore be appreciated that the elements of Figure 1 may be either analogue or digital components with appropriate signals being applied to the terminals 10, 13 and 14, suitable conventional signal conversion being utilized when necessary.

The computer of Figure 1 has been described in terms of discrete analogue or digital components. The present invention includes within its scope a programmed digital computer for implementing the function represented, for example, by equation (7). Referring now to Figure 2, a stored programme digital computer is schematically represented at 30 having the OMEGA positional data λ_o, the VOR/DME positional data λ_v and the range of the aircraft to the VOR/DME facility R applied at terminals 31, 32 and 33 respectively. The computer 30 is programmed in a manner to be described to provide the computed positional data λ_c as indicated by the legend. The embodiment of Figure 2 may operate in failure modes in a manner similar to that described above with regard to Figure 1 in response to a VOR/DME invalid signal at a terminal 34 and an OMEGA invalid signal at a terminal 35. It will be appreciated that signals of appropriate formats may be applied to the terminals 31 to 35 or suitable conventional conversion performed thereon by apparatus not shown or by well-known programmes stored within the computer 30.

Referring now to Figure 3, the step by step computation of the computed latitude λ_c performed by the computer 30 is illustrated. During each computation iteration, the computer enters the computational programme flow at 40 by going to the initial address of the computational sub-routine as stored in the memory of the computer 30. At block 41 of the flow chart the current value of the OMEGA data λ_o is corrected by adding the last stored OMEGA compensation δ to form a temporary computed latitude λ'_c. At block 42 λ'_c is subtracted from the current value λ_v of the VOR/DME latitude to determine the error therebetween, $\Delta\lambda$. In block 43 the gain k is computed as a function of the distance R from the VOR/DME facility where k_1 is a constant. In block 44 the latitude error $\Delta\lambda$ is multiplied by the gain k to obtain the intergrand A. In block 45 the integration is performed by multiplying the integrand A by Δt, the time since the last correction, and adding the result to the previous value of the OMEGA correction δ to form an updated δ. In block 46 the computed latitude λ_c is obtained by adding the updated OMEGA correction δ to the OMEGA derived latitude λ_o. Since block 46 completes a computational iteration the programme exits at 47.

It will be appreciated that the programme segments associated with each of the blocks 40 to 47 are readily prepared by a normally skilled programmer and will not be shown herein for brevity. It will

furthermore be appreciated that most of the legends within the blocks of Figure 3 are in the format of programme statements of a compiler programming language such as FORTRAN.

Referring now to Figure 4, a flow chart for the operation of the embodiment of Figure 2 in failure modes is illustrated. The programme enters at 50 and at 51 tests the state of the signal applied to the terminal 34 to determine if the VOR/DME data is valid. If the data is valid the programme proceeds to block 52 similarly to test the validity of the OMEGA data in response to the signal at the terminal 35. If both the VOR/DME and the OMEGA data are valid the programme proceeds to the block 53 wherein the computations discussed with regard to Figure 3 are performed. Since the computational interation is then complete, the programme exits at 54. If, however, the VOR/DME data is found to be invalid in the block 51, the programme proceeds to a block 55 which is similar to the block 52 in that the validity of the OMEGA data is tested. If the OMEGA data is valid, although the VOR/DME data is invalid, the programme proceeds to a block 56 wherein the computed latitude data λ_c is obtained by updating the current and valid OMEGA data λ_o with the last computed OMEGA compensation δ. The programme then proceeds to the exit block 54. If the programme reaches the block 52 and finds the OMEGA data invalid, although the VOR/DME data is valid, the programme proceeds to a block 57 that utilizes the VOR/DME data λ_v to provide directly the computed data λ_c, whereafter the programme proceeds to the exit block 54. If, however, neither the VOR/DME nor the OMEGA data is valid, the programme proceeds through the blocks 51 and 55 to a block 60 wherein dead reckoning computations are performed of the type discussed in the aforesaid U.S. Patent Specification No. 3,919,529, whereafter the programme proceeds to the exit block 54. It will be appreciated from the foregoing that the described embodiments utilize the OMEGA equipment operating in a relatively simple differential mode to provide high flight accuracy without the necessity for the usual complex and expensive diurnal error correction electronic circuitry. The VOR/DME positional data is given an authority which is an inverse function of the distance from the station. Within approximately ten miles from the station the VOR/DME data is used to update the OMEGA data. At large distances the OMEGA data displacement from the last update is utilized to provide the computed position with high accuracy and without propagation corrections.

WHAT WE CLAIM IS:—

1. A computer for use in aircraft and arranged or programmed to provide automatically a computed aircraft positional data signal in response to an OMEGA positional data signal from an OMEGA system, a VOR/DME positional data signal from VOR/DME apparatus tuned to a stationary VOR/DME facility and a range signal representative of the distance of the aircraft from the VOR/DME facility, the computer comprising first summing means which are responsive to the VOR/DME positional data signal and the computed positional data signal and which provide a positional data error signal representative of the difference therebetween, OMEGA compensation means which are responsive to the positional data error signal and the range signal and which provide an OMEGA compensation signal in dependence on the time integral of the product of the positional data error signal and an inverse function of the distance, and second summing means which are responsive to the OMEGA positional data signal and the OMEGA compensation signal and which provide the computed positional data signal in accordance with the algebraic sum thereof.

2. A computer according to Claim 1, wherein the OMEGA compensation means comprise gain adjusting means responsive to the positional data error signal and the range signal for providing the positional data error signal at a gain adjusted in accordance with the inverse function of the distance, and integrator means coupled to the gain adjusting means for providing the OMEGA compensation signal in accordance with the time integral of the gain adjusted positional data error signal.

3. A computer according to Claim 2 and further including means for clamping the integrator means in response to a signal indicative of invalidity of the VOR/DME positional data signal.

4. A computer according to any of the preceding claims and further including means for obtaining the computed positional data signal directly from the VOR/DME positional data signal in response to a signal indicative of invalidity of the OMEGA positional data signal.

5. A computer for use in aircraft and programmed to provide automatically a computed aircraft positional data signal in response to an OMEGA positional data signal from an OMEGA system, a VOR/DME positional data signal from VOR/DME apparatus tuned to a stationary VOR/DME facility and a range signal representative of the distance of the aircraft from the VOR/DME facility, the computer

being arranged to store a previous value of an OMEGA compensation signal, add the current value of the OMEGA positional data signal to the previous value of the OMEGA compensation signal to provide a temporary computed positional data signal, subtract the value of the temporary computed positional data signal from the current value of the VOR/DME positional data signal to provide a positional data error signal, compute a gain value in accordance with an inverse function of the distance, multiply the value of the positional data error signal by the gain value to provide an integrand value, multiply the integrand value by the time elapsed since the computation for the previous value of the OMEGA compensation signal and add the result to the previous value of the OMEGA compensation signal to provide an updated value of the OMEGA compensation signal, thereby performing a time integration of the positional data error signal at a gain determined by the gain value, and add the updated value of the OMEGA compensation signal to the current value of the OMEGA positional data signal to provide the computed positional data signal.

6. A computer according to Claim 1 or Claim 5, substantially as herein particularly described with reference to the accompanying drawings.

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Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1978
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1528180 COMPLETE SPECIFICATION

2 SHEETS

This drawing is a reproduction of the Original on a reduced scale

Sheet 1

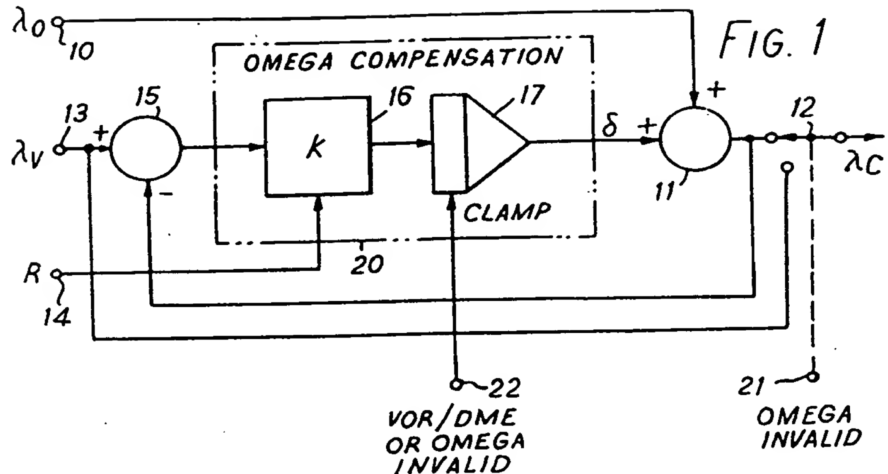

FIG. 1

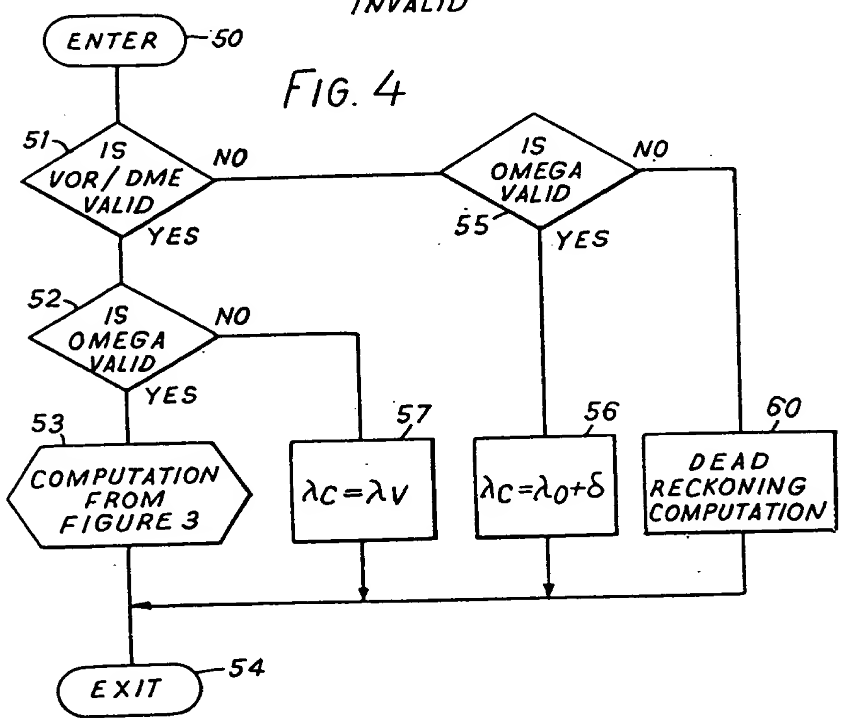

FIG. 4

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FIG. 3

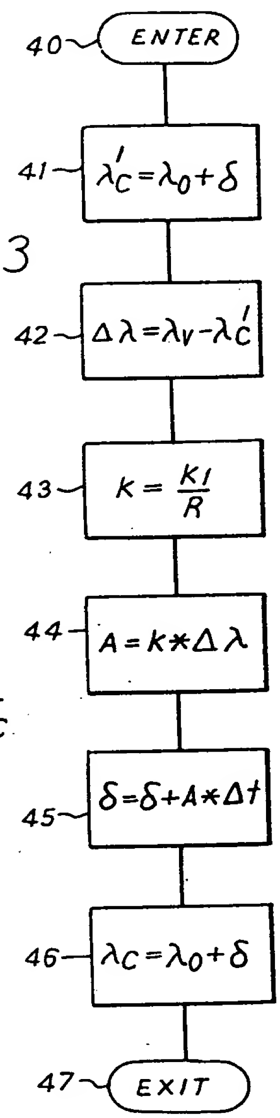
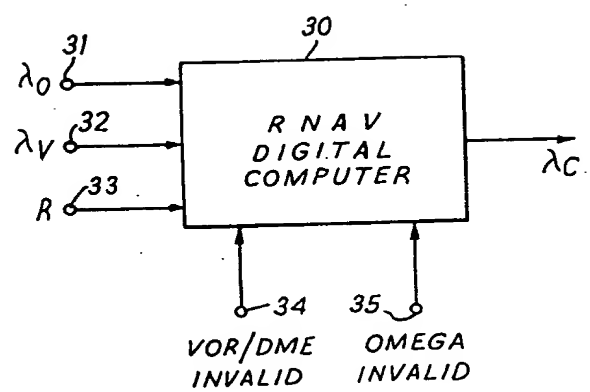

40
ENTER
41
$\lambda_C' = \lambda_0 + \delta$
42
$\Delta\lambda = \lambda_V - \lambda_C'$
43
$K = \frac{K1}{R}$
44
$A = K * \Delta\lambda$
45
$\delta = \delta + A * \Delta t$
46
$\lambda_C = \lambda_0 + \delta$
47
EXIT

FIG. 2


30
31
λ_0
32
λ_V
33
R
RNAV
DIGITAL
COMPUTER
λ_C
34
35
VOR/DME
INVALID
OMEGA
INVALID

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